

Improved Doppler Radar/Satellite Data Assimilation

Allen Zhao

Marine Meteorological Division, Naval Research Laboratory
7 Grace Hopper Ave, Mail Stop II, Monterey, CA 93943-5502
phone: (831) 656-4700 fax: (831) 656-4769 email: Zhao@nrlmry.navy.mil

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<http://www.nrlmry.navy.mil>

LONG-TERM GOALS

Our goal is to develop a short-term high-resolution data assimilation capability that can provide the Navy with improved analyses and forecasts of atmospheric conditions with sufficient detail and accuracy for supporting the Navy mission in threat detection, weapons development, and weather safe operations. The data assimilation system will utilize all available weather data, such as Doppler radar, in situ, and remotely sensed observations. The system will run efficiently and generate a detailed analysis of the atmosphere with sufficient accuracy to predict target area weather conditions. This information can then be fed back to weapon system operators to improve detection and strike capabilities.

OBJECTIVES

The objective of this research is to build an advanced high-resolution data assimilation system for the on-scene (OS) version of the Coupled Ocean/Atmospheric Mesoscale Prediction System (COAMPS[®]), and at the same time, investigate the impact of high-resolution data assimilation on short-term mesoscale numerical weather prediction. This data assimilation scheme will be able to analyze mesoscale and storm-scale weather by applying sophisticated analysis procedures capable of ingesting the information from Doppler radar, satellite, and other remote sensors. The primary focus of this effort will be to design a system that optimally utilizes the available weather data such as DoD Doppler radar data for initializing COAMPS-OS[®].

APPROACH

The Naval Research Laboratory (NRL), through collaborations with universities, is developing a high-resolution data assimilation system. The system includes a variational approach for Doppler radial velocity data assimilation that uses the background fields provided by atmospheric predictions from COAMPS at non-synoptic times and/or analyses from the newly developed NRL Atmospheric Variational Data Assimilation System (NAVDAS) at synoptic times. Variational approach with a simplified adjoint method is used to achieve the high computational efficiency needed to assimilate high-resolution data from Doppler radars (including DoD radars on ships and at forward-deployed locations). The analysis increment fields are expressed by B-spline basis functions to optimally filter noise while the analysis is performed directly on the COAMPS grid. The assimilation time window is synchronized with COAMPS integration time steps and radar volumetric scans to enhance the coupling

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14. ABSTRACT Our goal is to develop a short-term high-resolution data assimilation capability that can provide the Navy with improved analyses and forecasts of atmospheric conditions with sufficient detail and accuracy for supporting the Navy mission in threat detection, weapons development, and weather safe operations. The data assimilation system will utilize all available weather data, such as Doppler radar, in situ, and remotely sensed observations. The system will run efficiently and generate a detailed analysis of the atmosphere with sufficient accuracy to predict target area weather conditions. This information can then be fed back to weapon system operators to improve detection and strike capabilities.					
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of the model with the data. To compliment the radar assimilation system, the cloud information from high-resolution geostationary satellite observations (such as the infrared and visible imagery), and surface cloud observations is also fused and assimilated to enhance the cloud analyses in the model initial fields.

WORK COMPLETED

During the fiscal year of 2007, researches for this project were continuously focused on studying the impacts of radar and satellite data assimilation on mesoscale NWP model forecasts. Several studies have been conducted with coordination and collaborations with other research projects. One of the major efforts was the extensive test of the radar data assimilation algorithms developed jointly by NRL and the University of Oklahoma. Several types of storms have been selected to test the system and to assess the values of radar data on high-impact weather prediction. Experiments were also performed to study the sensitivity of the impacts of radar data assimilation to model grid resolution.

An extensive study of the satellite-derived cloud information on model forecasts was also carried out. This was done by assimilating the three-dimensional cloud liquid water and ice contents retrieved from GOES satellite infrared and visible channels using the cloud analysis system from the ARPS Data Assimilation System (ADAS) into the COAMPS to initialize the model initial cloud fields. The experiment was conducted in a real-time parallel test mode for about three weeks. The impacts of satellite data assimilation on model forecasts were evaluated by looking at individual cases and by calculating the statistics of verifications for the whole experimental period.

Acquisition, processing, quality control and assimilation of the SPS-48E shipboard radar data were also the major achievements of this project during the last year. Reflectivity data from the SPS-48E radar at the land-based test site at Dam Neck, Virginia have been processed, quality-controlled and assimilated into COAMPS with positive impacts on storm forecasts. Reflectivity and Doppler radial velocity data from the SPS-48E collected by the prototype Hazardous Weather Detection and Display Capability (HWDDC) during the USS PELELIU's encounter with hazardous weather near Hawaii on February 22, 2006 are also being processed. Some quality control issues specifically related to shipboard radars are under study. These data will be assimilated into COAMPS soon to demonstrate the impacts of meteorological information retrieved from "through-the-sensor" observations on battlespace environment prediction.

Efforts continue to systematically improve the high-resolution data assimilation system. A hybrid data assimilation system is currently under development, in which the ensemble-based approach is taken to estimate the flow-dependent initial background error covariance and model forecast error covariance at mesoscale and storm-scale. Meanwhile, the analyses from the variational method are used to continuously update the ensemble mean to keep the ensemble and variational systems fully coupled.

RESULTS

The radar data assimilation algorithms have been extensively tested with case studies from various types of storm systems, ranging from supercell thunderstorms with a typical storm size of about 50 km to a hurricane case with a spatial scale of about 1,000 km. The values of radar data added to the analyses and forecasts of the storm systems are objectively assessed by comparing these analyses and forecasts with observations. It has been found from our study that the assimilation of radar data (both reflectivity and radial velocity) had significant impacts on storm dynamical and microphysical

structure analyses. Figure 1 gives vertical cross-sections of total precipitation mixing ratio (TPMR, defined as the sum of rain, snow and graupel mixing ratios in g/kg) of COAMPS analysis fields of a storm system with and without radar data assimilation and the radar reflectivity fields computed from TPMR vertical cross-sections. For comparison, the observed radar reflectivity vertical cross-section is also given in Fig. 1e. It is obvious that the analysis without radar data assimilation has large amount of precipitation (with a maximum value of about 2.5 g kg^{-1}) near 6 km while radar observations show strong reflectivity areas near the surface. With the reflectivity data assimilation, the maximum TPMR regions have been shifted downward to the surface. Another outstanding contrast between Fig. 1a and 1b is the magnitude of TPMR. The maximum value TPMR in the eyewall is reduced to between $0.6\text{-}0.8 \text{ g kg}^{-1}$ after the reflectivity assimilation cycles. There is a similar impact on the derived radar reflectivity fields from the reflectivity assimilation (Figs. 1c and d). In regions far from the storm center, the corrections are also notable, though not as remarkable as those near the storm center because of the missing radar data at the bottom of the storms due to the long distances from the radar stations.

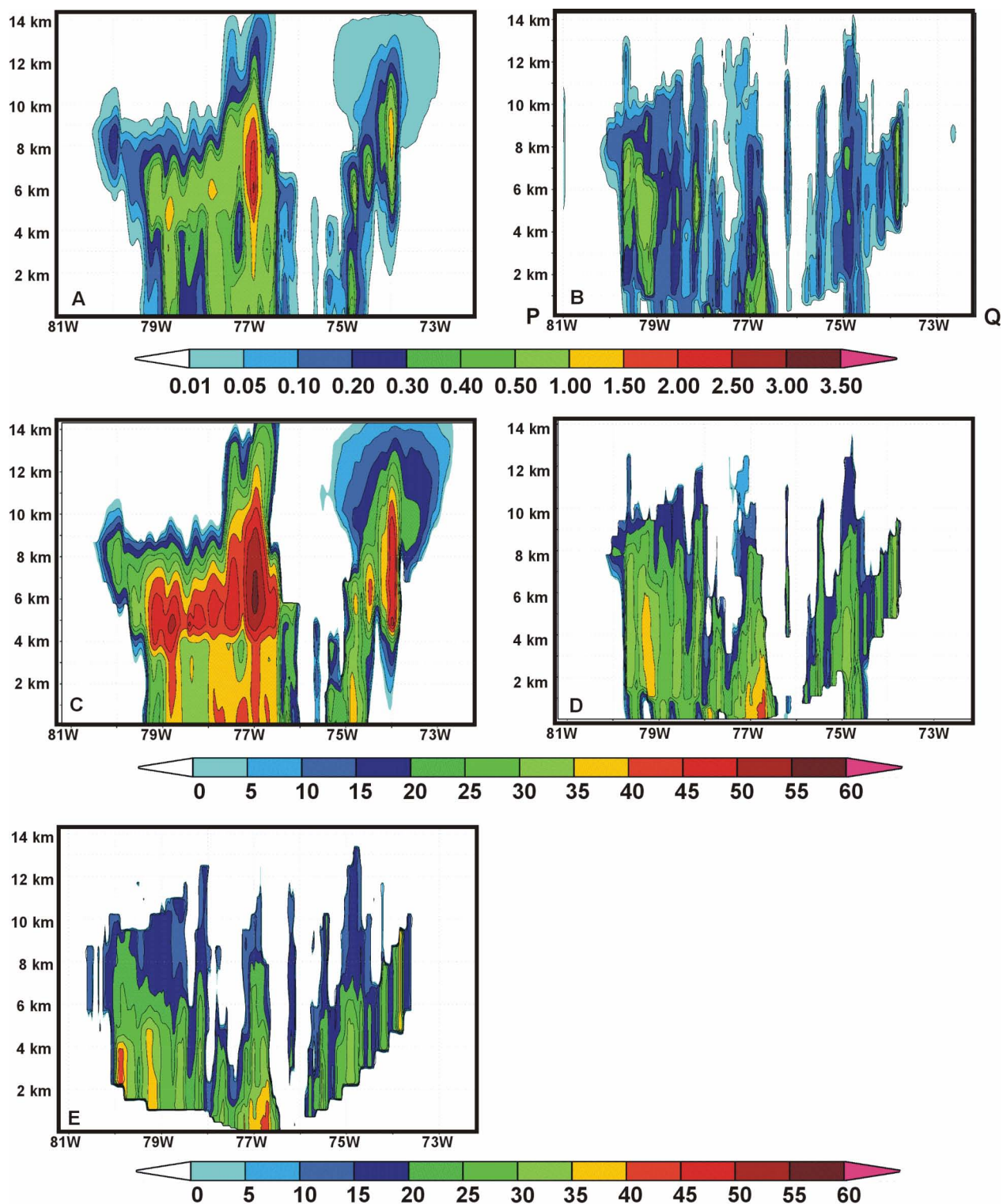


Figure 1. (A) Vertical cross-section of total precipitation mixing ratio (TPMR, g/kg) from COAMPS analyses without radar observations; (B) As in (A) except with radar observations; (C) Radar reflectivity (dBZ) calculated from (A); (D) As in (C) except calculated from (B); (E) Observed radar reflectivity.

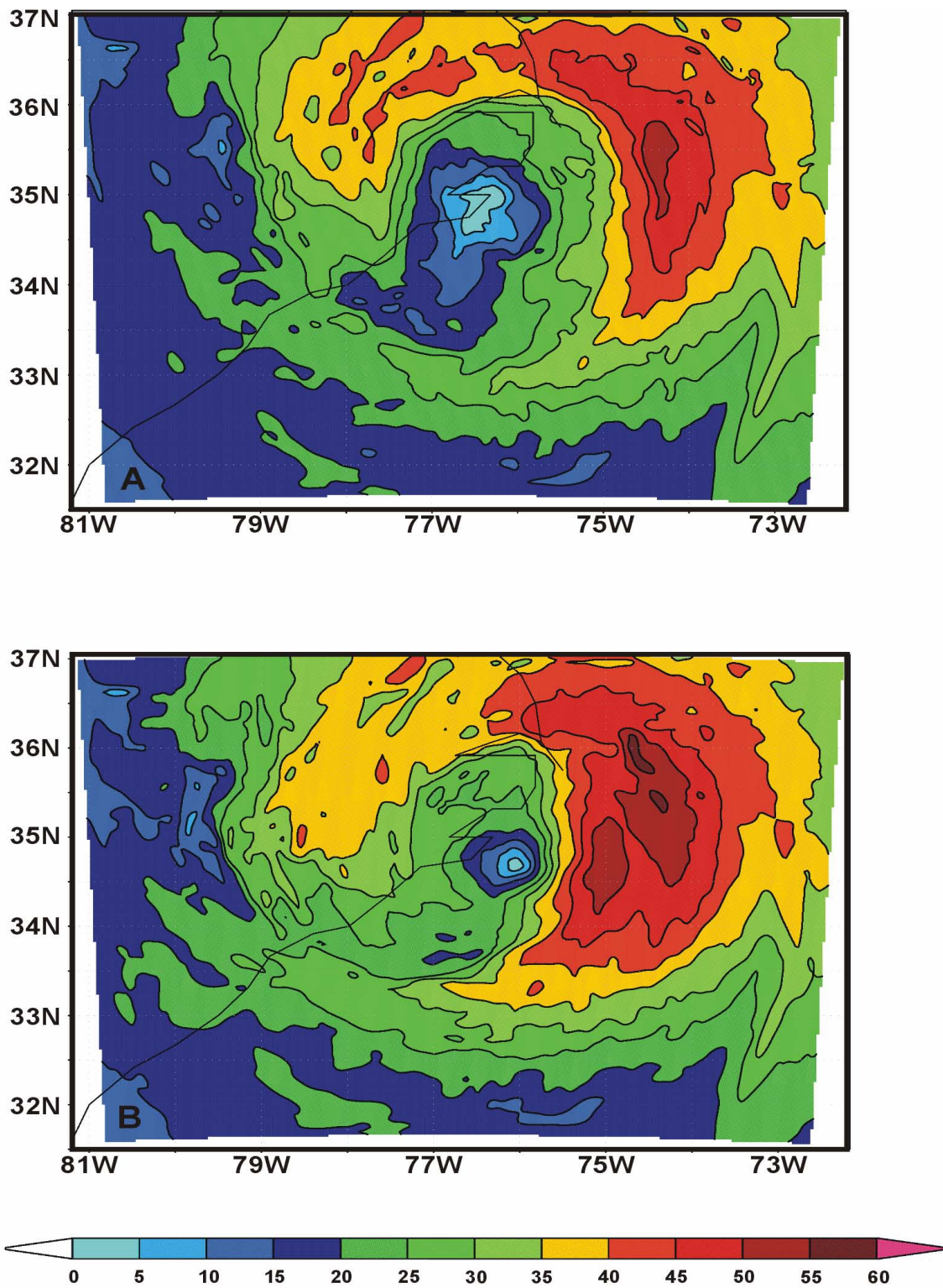


Figure 2. *Horizontal cross-section of horizontal wind speed (m s⁻¹) of Hurricane Isabel (2003) at 2 km above the surface at the end of the data assimilation period (valid for 1600 UTC 18 September) from (a) COAMPS analyses without radar observations, and (b) the analyses with radar observations.*

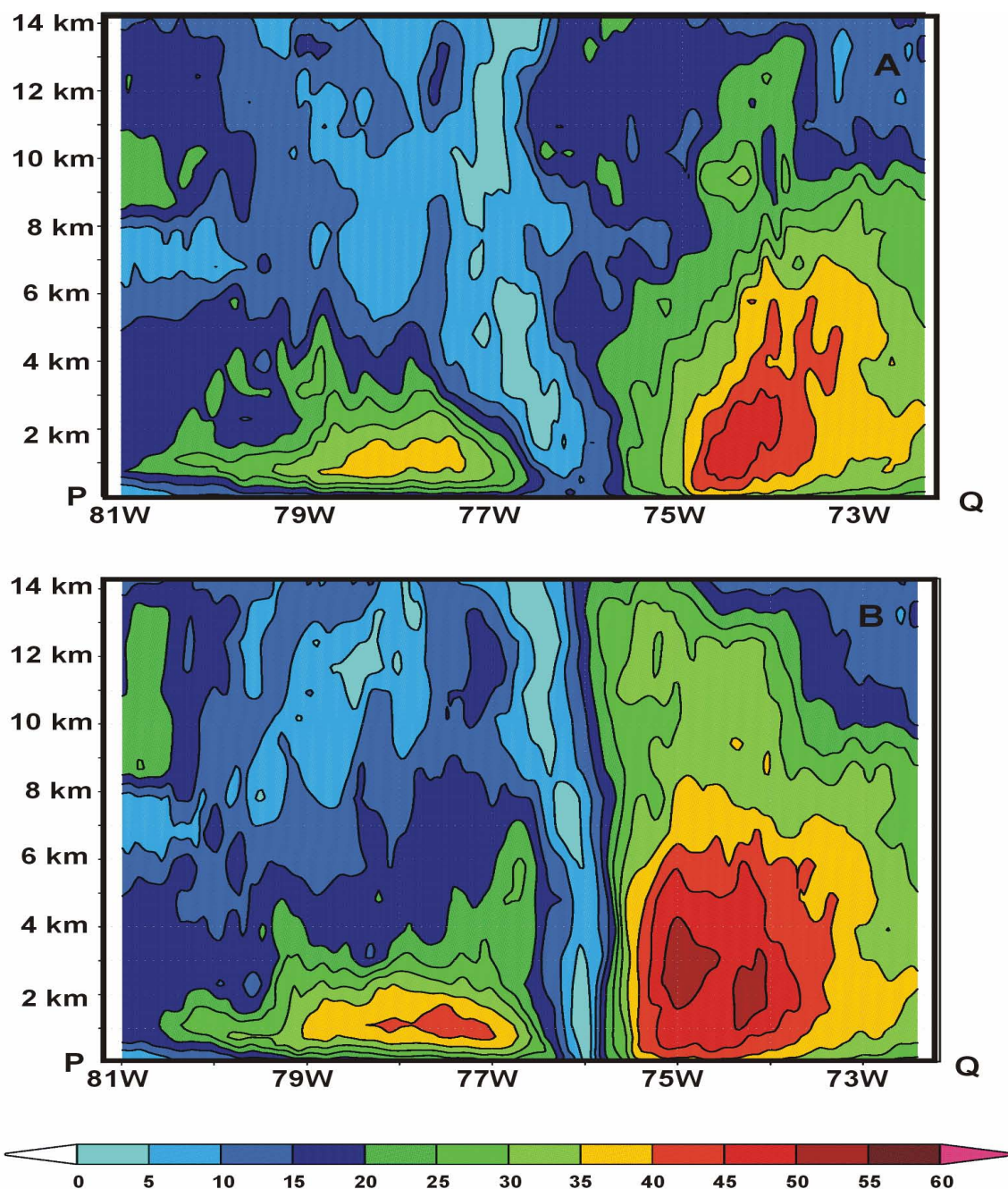


Figure 3. Same as Figure 2 except for vertical cross-sections.

Significant changes in storm dynamical structure analyses also resulted from radar data assimilation. Figure 2 shows horizontal cross-sections of horizontal wind speed analyses at 2 km above the surface of Hurricane Isabel (2003) at 1600 UTC 18 September 2003 with and without radar data assimilation while Fig. 3 gives the vertical cross-sections through the hurricane eye. As you can see in Fig. 2, the hurricane inner core is organized into a much tighter structure after the radar data assimilation. Also, the maximum wind speed at this level increases by about $5\text{--}10\text{ m s}^{-1}$ and the area of wind speed exceeding 50 m s^{-1} expands substantially in Fig. 2b. These changes are also obvious in the vertical

cross-sections of horizontal wind speed shown in Fig. 3. The wind speed with radar data assimilation increases by 5 m s^{-1} on both the east and west sides of the hurricane eye (Fig. 3a vs. Fig. 3b). Corresponding to the tighter inner core structure seen in the horizontal cross-section in Fig. 2b, there is also a large gradient in wind speed across the eyewall on the east side (see Fig.3b), and the vertical tilting of the eyewall on the west side in Fig. 3a is reduced to a large extent in Fig. 3b. The hurricane has been intensified by the data assimilation to near the strength of observed category 2 hurricanes.

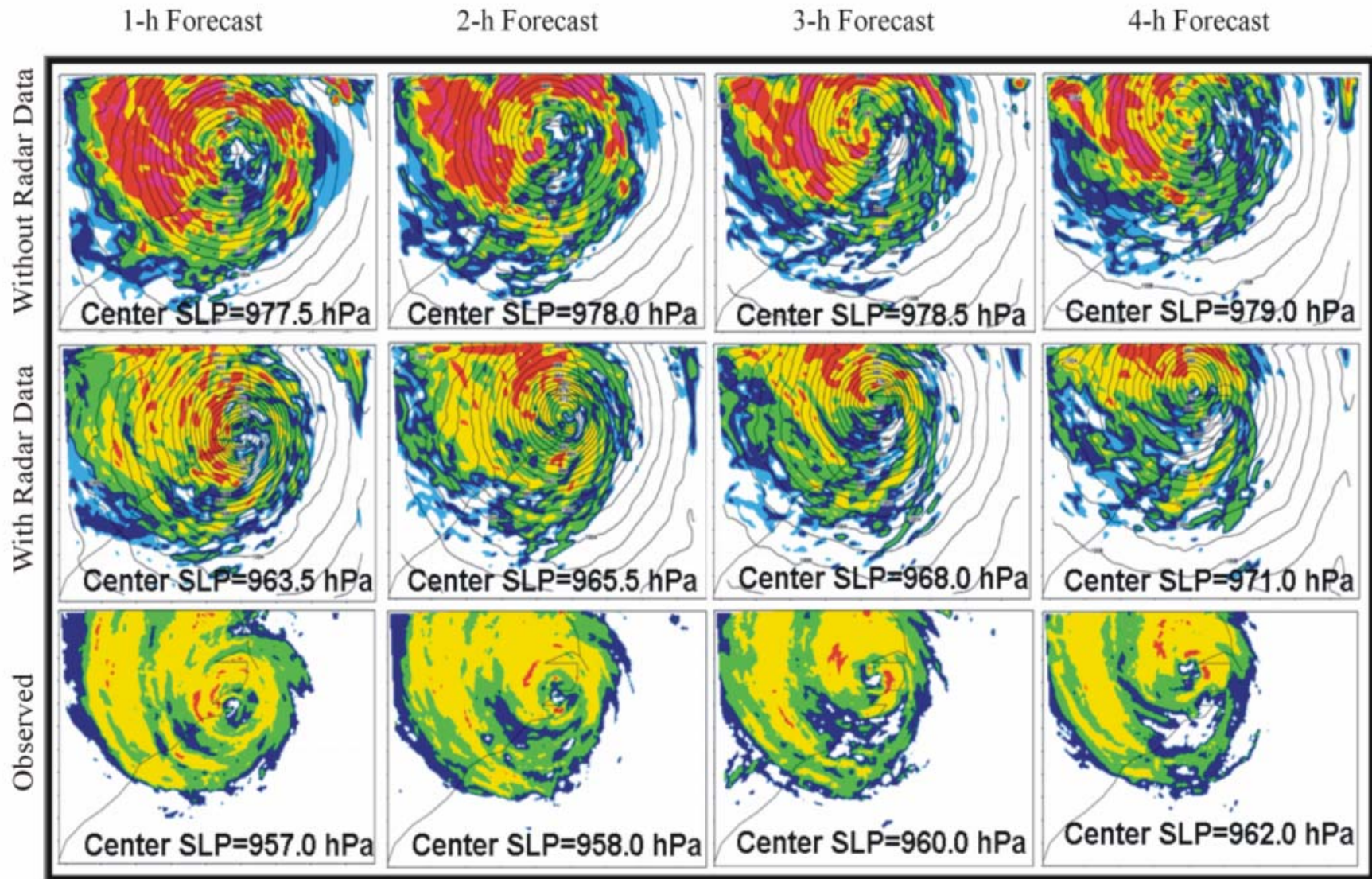


Figure 4. Radar composite reflectivity (dBZ) and sea level pressure (hPa) fields of Hurricane Isabel (2003) from COAMPS forecasts with and without radar data assimilation. The numbers are hurricane center sea level pressures. The observed radar composite reflectivity and center sea level pressures during the same time period are also given for comparison.

The assimilation of radar data into COAMPS model also show very encouraging results with remarkable improvement in storm prediction. These improvements have been observed almost in all the case studies we conducted. As an example, Fig. 4 gives the first four hour forecasts of sea level pressure and composite reflectivity from COAMPS model initialized with and without radar data assimilation for Hurricane Isabel (2003) case. For comparison, the observed radar composite reflectivity fields and hurricane center sea level pressures are also given. The radar reflectivity forecasts from the experiment without radar data assimilation are much higher compared to the observed. The over-prediction, however, is effectively corrected by the radar data assimilation so that the reflectivity forecasts in the radar data assimilation experiment are significantly adjusted in magnitude toward the observations. The forecasts from radar data assimilation experiment also show remarkable improvements in the intensity and structures of the hurricane manifest in the well-organized hurricane eye with lower central sea level pressure and stronger horizontal gradient and in the higher wind speed at and above the surface as well. The rainbands in the forecasts with radar data assimilation appear much better organized and closer to the observations near the eyewall than those in control experiment.

Studies were also conducted to investigate the sensitivity of storm forecast improvements resulted from the radar data assimilation to model resolution. Two radar data assimilation experiments for the Hurricane Isabel (2003) case were performed with 6 km and 3 km grid resolutions, respectively. Figure 4 presents the improvements in hurricane center sea level pressure forecasts over the two COAMPS control runs (also with 6 km and 3 km grid resolutions, respectively) as a function of forecast hours. It is appears that the improvements in hurricane center sea level pressure forecast from the 3 km experiment are much larger at the beginning but decrease more quickly with the forecast hour than the 6 km. At about the sixth hour, both experiments show improvements of basically the same magnitude. The reason is still unknown.

Satellite-derived three-dimensional cloud liquid water and ice mixing ratios from ADAS analyses were also assimilated into COAMPS to update the model initial cloud fields. This experiment was designed and carried out in a real-time parallel test mode for about three weeks. Table 1 shows the mean forecast errors and RMS errors of the forecasts of 2-m temperature, 2-m dew temperature, 10-m wind speed, and 10-m wind direction from both the control runs and the experiments verified against surface observations during the whole experiment period of 1-23 April 2007. Improvements in surface temperature, moisture and wind forecasts with satellite cloud data assimilation are obvious over ocean while over land, the results are somehow mixed. However, the overall results are very encouraging.

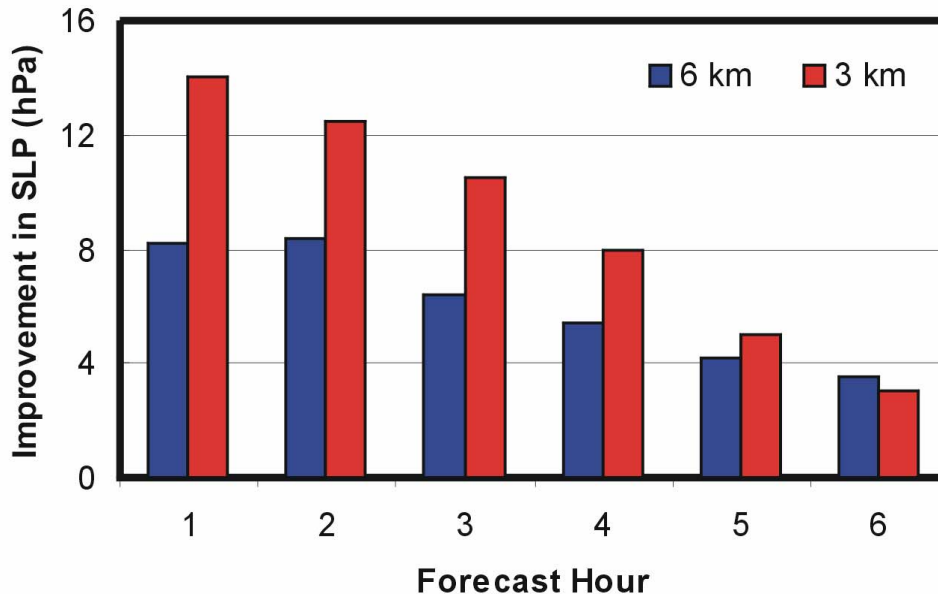


Figure 5. Improvements in hurricane center sea level pressure forecasts from 3 km (red) and 6 km (blue) COAMPS runs with radar data assimilation.

IMPACT/APPLICATIONS

The hourly-cycled high-resolution data retrieval and assimilation system developed at NRL for radar, satellite and surface observations for the COAMPS model will provide the Navy, through the NRL NOWCAST system, with near real-time, three-dimensional cloud and wind analyses and very short-term (0-6 hours) theater-scale weather forecasts in any region of interest to support the Navy's mission. The technology was demonstrated during Fleet Battle Experiment – Juliet with products providing up-to-date, detailed information to tactical decision makers about the three-dimensional atmospheric battlespace conditions. The high-resolution winds from both the data assimilation system and the COAMPS model forecast are also used to drive chemical/biological (CB) dispersion models, which are used for assessing contamination avoidance and decontamination strategies. While focusing on battlespace environmental applications, this work also establishes a scientific framework for utilizing radar-derived meteorological information in nowcasting and numerical weather prediction applications.

Table 1. Mean Forecast Error (Forecasts-Observations) for The Nest-3 Grid (5 km) Domain

(1 April 1007 – 23 April 2007, verified every 6 hours)

	2m T (degree)	2m Td (degree)	10m Wind speed (m/s)	10m Wind direction (degree)
CNTL (Over Ocean)	0.35	1.28	-3.6	15.4
ADAS DA (Over Ocean)	0.11	0.98	-3.08	9.5
CNTL (Over Land)	0.96	0.34	-1.46	16.2
ADAS DA (Over Land)	0.88	0.67	-1.25	12.2
CNTL (ALL)	0.84	0.36	-1.84	16.1
ADAS DA (ALL)	0.74	0.64	-1.58	11.7

RMS Error for The Nest-3 Grid (5 km) Domain
(1 April 1007 – 23 April 2007, verified every 6 hours)

	2m T (degree)	2m Td (degree)	10m Wind speed (m/s)	10m Wind direction (degree)
CNTL (Over Ocean)	1.91	2.52	4.47	55.6
ADAS DA (Over Ocean)	1.85	1.74	3.99	36.0
CNTL (Over Land)	3.37	2.93	2.94	68.0
ADAS DA (Over Land)	3.53	3.07	2.81	44.1
CNTL (ALL)	3.15	2.92	3.27	65.9
ADAS DA (ALL)	3.29	3.05	3.05	42.7

Blue – Control run

Red – improved

Black - worse

TRANSITIONS

The ADAS cloud analysis and cloud verification system have been integrated into COAMPS-OS V1.6.4, which has been transitioned to CAAPS at FNMOC in 6.4 programs.

PATENTS

NRL Three-Dimensional Radar Reflectivity Mosaic System (pending).

RELATED PROJECTS

Related NRL base projects include BE-435-047, Advanced Assimilation of Non-conventional Data for Improved High-Impact Weather Prediction and BE-435-003, Probabilistic Prediction of High Impact Weather. Other related projects include Radar Data Quality Control and Assimilation

At the National Weather Radar Testbed (NWRT) (ONR, N000140410312), 6.4 Reach-Back Doppler Radar Data Assimilation (PMW 180, X2341) and 6.4 On-Scene Tactical Atmospheric Forecast Capability (PMW 180, X2342).

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